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## Particle Cloud Mixing in Microgravity

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**NASA**

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## Abstract

Quasi-steady flame propagation through clouds of combustible particles requires quasi-steady transport properties and quasi-steady particle number density. Microgravity conditions may be employed to help achieve the conditions of quiescent, uniform clouds needed for such combustion studies. Joint experimental and theoretical NASA-UCSD studies have been concerned with the use of acoustic, electrostatic, and other methods of dispersion of fuel particulates. Results of these studies are presented for particle clouds in long cylindrical tubes.

## 1 Introduction

Experimental study of the combustion properties of clouds of combustible particles (in an oxidizing gaseous medium) requires the initial establishment of a suitably uniform cloud. It has been argued that suitably quiescent and uniform particle clouds are most easily achieved under microgravity conditions where gravitational sedimentation processes can be suppressed.<sup>1</sup>

Vigorous mixing (to achieve cloud uniformity) can be obtained through a variety of techniques, including mechanical, acoustic and electrostatic. This paper reports the experimental use of the latter two methods. Where acoustic mixing is employed, triboelectric particle-particle interaction effects,<sup>2</sup> tend to promote agglomerative growth of nonmonomeric clusters. Correspondingly, particle depletion of the gas-suspended cloud may be due to particle adhesion to container walls. The suppression of both these unwanted, acoustically-induced particle-particle and particle-wall interactions may be achieved by limiting the acoustic mixing to a very short time. To achieve adequately uniform particle clouds through use of very short periods of acoustic mixing is difficult. Acoustic power must be high, to help induce the substantial secondary air flows needed for mixing. High acoustic power also helps to establish the nonlinear interactions needed for the excitation of the various mixing modes: longitudinal, radial and tangential.

This paper reports on studies concerned with the use

of high power, short period acoustic bursts to achieve good mixing as well as suppressed agglomerative and particle-wall interactions. Various calibration methods for measuring the concentration of particles are discussed in Appendix 1. Also reported are some preliminary results for the use of electrostatic methods of particle cloud dispersion (Appendix 2) as well as the calculated results for the deagglomerative effects of alpha-particle fields (Appendix 3).

## 2 Experiment and Instrumentation Description

Figures 1 and 2 show the components and sequential operation of the flame tube. The eventual experiment is run in four stages:<sup>3</sup> (1) an acoustic driver is turned on to mix the particles into a uniform cloud; (2) the driver is turned off, and secondary air flows are given time to decay; (3) a nitrocellulose igniter is powered, burning through a mylar diaphragm and igniting the particle cloud; and (4) the flame spreads axially down the tube length, as in any premixed fuel system. This paper describes the techniques employed in the first two stages, as investigated in recent experiments performed at gravity levels on the order of  $10^{-5}g$  in the LeRC 2.2 second drop tower facility.

In this facility, the experimental hardware, as shown in Figure 3, is mounted within the confines of a drop rig (maximum allowable dimensions of approximately 38 inches L by 14 inches W by 28 inches H). The drop rig itself is placed inside a drag shield; both the drag shield and drop rig are suspended by a thin wire at the top of a 100 foot open shaft. When the wire is cut pneumatically, both drag shield and drop rig fall for 2.2 seconds, landing in an aerated sand pit. During the fall, the drag shield absorbs most of the air drag, while the drop rig falls freely inside (see Figure 4). In this way, the low gravity level cited above is achieved during the fall.

The experimental hardware consisted of: (1) a 25 inch length by 2 inch diameter tube containing 480 mg lycopodium (an equivalence ratio of about 3); (2) a 1 inch length inline igniter section; (3) a 2 inch heat ex-

changer to cool the combustion products as they escaped through, the open tube end; and (4) an 80 watt capacity acoustic speaker mounted inline on the opposite end of the tube from the igniter.

Instrumentation consisted of: (1) two high speed movie cameras each filming one half of the tube from above and through a mirrored side view; and (2) four concentration detector assemblies mounted 4, 17, 31.5, and 45.5 cm from the igniter end of the tube. Each assembly, shown in Figure 5, contains a light emitting diode (820 nm), filters and collimating lenses, and a photodiode to measure the strength of the 3.5mm diameter light beam. The signal strength is determined by the particle concentration in the beam path. In order to improve accuracy, each beam is split to provide an unattenuated reference voltage signal. Additionally, the LED is pulsed on/off to account for any ambient light leaks and drift. To account for possible circumferential effects, the four detector assemblies are mounted at different angles passing through the tube axes. The signals from the detector assemblies, normally between 0 and -10 volts, are halved and inverted to be compatible with the central data acquisition system described below. Liquid suspension tests in normal gravity and other drop tower tests to calibrate the detector are described in Appendix 1.

Prior to the experiment, the fuel was positioned in the tube via a small grooved rod. The fuel particles were arranged in a thin row (4-10mm wide), running the full axial length of the tube; the reasons for selecting this initial position will be discussed later. The experimental sequence then is as follows: (1) while still hanging from the thin wire, the cameras and lights are powered and brought to normal operating speed; during this period the detector assemblies are sampled at a rate of 12.5 Hz; (2) the thin wire is cut, and the package begins to fall; (3) at 0.05 seconds into the reduced gravity period, the acoustic speaker is turned on; it is driven with a square wave signal at 140Hz for a period of 0.5 seconds; (4) immediately after the speaker is turned off, the detector assemblies are sampled at a rate of 25Hz (25 "LED on" readings and 25 "LED off" readings); (5) at 2.1 seconds into the drop, the data acquisition system and cameras are stopped.

All data acquisition and control functions are provided by a battery powered microprocessor-based system, based on a commercially available board.<sup>5</sup> After the drop is completed, detector data stored in memory on this board is downloaded to a personal computer and processed via a spreadsheet program. The data collected prior to the drop provide the "unattenuated" reference voltage and are compared to the drop measurements of the signal attenuated by the suspended particle cloud.

### 3 Results

Figure 6 shows selected frames from the film records of the drop. Immediately after the speaker is turned on, the fuel particles are scrubbed off the tube bottom, bursting into regularly spaced, narrow airborne particle columns. These columns quickly merge with their nearest neighbor, creating regular spaces of clouds and voids. Nearest neighbors then merge again, creating broader, but still distinguishable columns of fuel and voids. While the speaker is still running, i.e. within the first 0.5 seconds of reduced gravity, the columns can be seen to oscillate axially in phase with the speaker. However during this same time period, the void spaces are filled partially as the columnar clouds diffuse and overlap with their nearest neighbors, and the cloud can be seen to move across the full tube diameter. When the speaker is turned off, a rush of secondary air flow swirls the particles sufficiently to fill in the remaining void spaces. This airflow then begins decaying and the particle cloud tends toward quiescence. However, complete quiescence is not achieved in 2.2 seconds of available reduced gravity time, based on the qualitative observations of film.

Figure 7 displays the data collected by the detectors in six different drop tests. In the early drops only two detectors were deployed. No data are collected during the time in which the speaker is powered, due to the restrictions of the data acquisition and control system. The predrop data show that the detectors are quite stable (less than 1% variation), providing a reference "unattenuated" signal. The postdrop data show that mixing occurs even after the speaker is turned off, via the secondary air flow mechanism. Though not steady, the detector signals are relatively unchanged for the last 0.5 to 1 second of the drop. In two cases, ambient light leaks into the detector caused erroneous signals at detector M4. This was concluded from data taken with the LED off; as such the M4 data should be ignored in drops 13 and 15. Drop 10 had visibly poorer mixing, a puddle of unmixed fuel being found under one of the detectors.

Figure 7 shows all the data which have been collected in this tube length; any conclusions should be viewed as preliminary. Nonetheless, the figure suggests an axial uniformity of  $\pm 10\%$  (as measured by the detectors), can be achieved for this stoichiometry in two seconds of reduced gravity time.

The "speaker on" time was varied in a few uninstrumented drop tests. If the speaker was powered for too short a time period, the scrubbing process was incomplete, and puddles of fuel unmoved from their initial position could be seen on film and on postdrop examination of the tube. Earlier tests in normal gravity revealed that excessively long "speaker on" time caused both severe particle adhesion to the wall and voids near the ends of the tube. At this point, the appropriate

speaker on time has been found to be between 0.5 and 0.8 seconds.

## 4 Discussion of Results

The short time in which the speaker is operating and the initial particle positioning have several advantages. First the problem of particle adhesion and agglomeration, as discussed by Berlad 1987, is minimized since the number and frequencies of particle collisions is minimized. It may be possible in the eventual combustion experiments to avoid the need for special techniques<sup>2</sup> to reduce adhesion to acceptable levels. Secondly the initial particle position reduces the time and difficulty to create uniform axial distribution of particles radially and circumferentially while minimizing axial migration. Thirdly the total experiment time is made small which may eventually allow the complete experiment to be conducted in LeRC aircraft or other ground-based reduced gravity facilities. The observed mechanism of mixing may (at first) appear surprising. Although the speaker was operated nominally at 140 Hz, i.e. near the first half wavelength of the tube, the discrete and regularly spaced columns suggest higher frequency excitation of the particles. At first it was thought that the speaker was providing higher harmonic signals due to square wave input. However, the above mixing process was observed independently in the detector calibration tests described in Appendix 1 which employed a pure sine wave input, as well as a different tube length, input frequency, speaker type and power, and custom driver circuitry. Although the principal acoustic driver frequency corresponds to the first longitudinal mode of the tube, its high power and the "sloppy" diaphragm at one tube end makes the acoustic resonator a highly nonlinear system. Wandering of energy among longitudinal, radial and tangential modes is a well known phenomenon characterizing nonlinear systems. That is, seemingly orthogonal normal modes do interact. The higher harmonics of the longitudinal mode appear to be stimulated in a manner that corresponds closely to the striations observed in the classical Kundt's Tube Experiment.<sup>6</sup> The correspondence of Kundt's Tube striations (of cork dust) and those observed herein for lycopodium is striking. To quote from reference [6] [pages 44-45], "...Perhaps the most striking of all effects of alternating aerial currents is the rib-like structure assumed by cork filings in Kundt's experiment. Close observation, while the vibrations are in progress, shews that the filings are disposed in thin laminae transverse to the tube and extending upwards to a certain distance from the bottom. The effect is a maximum at the loops, and disappears in the neighborhood of the nodes. When the vibrations stop, the laminae necessarily fall..." In microgravity, the "thin laminae" can rise to the top of the horizontal tube. When vibrations stop, our observed "laminae" do not necessarily fall. Higher har-

monics of the longitudinal mode do not, by themselves, account for the effective, rapid wall scrubbing of the lycopodium particles, distributed initially in a thin strip at the bottom of the horizontal cylindrical tube. The nonlinearity of the system permits energy coupling (destruction of the orthogonality) of the vibrational modes, permitting energy to be pumped into both radial and tangential modes. It is well known<sup>7</sup> that the tangential modes correspond to higher frequency spinning waves near walls and that radial waves may involve "sloshing". The "puddles" observed in a number of cases (e.g. run #15) correspond to the scouring of the tube wall in the form of double crescents, as if created by spinning flows in the neighborhood of walls. Three dimensional flows of this kind appear to provide the secondary flow conditions needed for good particle mixing, after cessation of the acoustic source.

The cloud concentration is measured at only four discrete locations. As in any experiment, it is impossible to measure concentration at every point in the system and this introduces some uncertainty in the uniformity determination. Care has been taken to position the detector assemblies to view through different axes of the tube diameter; additionally the uneven axial spacing of the detectors was intended to prevent false agreement between detectors in the cellular mixing process. However in about one third of the drop tests, a few, small (less than 1cm) puddles of unmixed fuel were observed on film and in post-drop tube examination while the detector data suggested a uniform cloud. The size of these clouds was on the order of the initial column spacing seen early in the mixing time. These puddles were confined to less than 5% of the tube volume, did not appear in every test and were not sufficient to prevent flame propagation (observed in tests not reported in this paper; as such these puddles should not affect the eventual combustion experiment). However the appearance of these puddles was not predicted by the examination of the detector data. Many more detector assemblies would be necessary to observe this phenomenon directly. Instead a combination of detector data and visual observation of film data can provide sufficient information to determine gross defects in the cloud uniformity. Eventually, the flame shape and speed which is sensitive to local concentration will provide more information about cloud uniformity.

To improve interpretation of the available detector data, a "conservation of mass" criterion might be applied. As one detector signals a diminished particle concentration, some other detector should signal an increase. An examination of the data reveals that is not always observed. This is due to the cellular or nodal nature of the mixing process. During the time the speaker is on, there is only small diffusive axial movement of particles, the nature of the mixing is such that the effect of a lack of mixing near one end of the tube is not transmitted to the other end. Better communication is

achieved after the speaker is turned off. The secondary air flows merge the various cloud columns together. The short reduced gravity test time is not sufficient to determine if the secondary air flow is also cellular in nature. If it is cellular, then imperfect communication between all parts of the tube may result and the conservation of mass criterion may be difficult if not impossible to interpret. If it is not cellular, then with more reduced gravity time a more uniform cloud may result. In longer duration tests if puddles of unmixed fuel are observed, then the detector data should reveal a lower concentration than in tests with more robust mixing. Plans have therefore been made to repeat this experiment on the LeRC Lear jet which provides between 10 and 20 seconds of reduced gravity time.

## 5 Problems and Future Plans

Though of minor consequence, the unmixed fuel puddles should be eliminated. Seemingly identical tests produced slightly different results. The problem may be due to poorly charged batteries, diaphragm positioning, improper fuel loading, ambient temperature changes, and nonreproducible speaker response. In the future, this problem will either be resolved, or "lived with"; unsuccessful tests are readily determined, and will be repeated until successful. It appears certain that more reduced gravity time will be required to conduct the complete experiment. The longer reduced gravity duration obtained on LeRC aircraft will overcome this problem; however gravity levels will be degraded about three orders of magnitude. This is not believed to be a serious problem for the eventual combustion experiment. Some particle wall adhesion tests need be done in both normal gravity and drop tower to quantify the extent of particle adhesion.

## 6 Concluding Remarks

The use of acoustic, electrostatic, or other methods of particle dispersion (to achieve fuel particle cloud uniformity) involves the interaction of numerous physical processes, not all helpful. Frictional interaction of dielectric materials involves triboelectric effects, with corresponding particle-wall adhesion and particle-particle agglomeration as possible consequences. Accordingly, periods of mixing which are long enough to create such undesirable charge separation effects are to be avoided. In these experiments, it was observed that powerful acoustic bursts (of the order of 1/2 second) at the approximate frequency of a cylindrical tube's longitudinal first harmonic creates conditions for good particle cloud mixing. The total "burst" duration is short, avoiding substantial triboelectric effects. High acoustic power, coupled with the nonlinear (sloppy) membrane at the tube's terminus stimulates the nonlinear effects needed for good mixing.

## 7 Acknowledgements

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## 8 References

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## Appendix 1

### Calibration of Optical Probes

In order to determine the relationship between the suspended fuel concentration and the strength of the light beam signal, a calibration must be performed with a known concentration of particles in the beam path. In the present study, two independent methods are employed to obtain the calibration curves for the concentration of the particles dispersed in air as a function of the fraction of light attenuated by the particle cloud, namely: (i) liquid suspension measurements and (ii) drop-tower measurements. In the first method, an estimate for the absorption coefficient ( $k$ ) of the particles can be obtained from the measurements and

Beer's law ( $I/I_0 = A \exp(-kx)$ , where  $I/I_0$  represents the fraction of light transmitted through a sample of two-phase mixture contained in a test blank of length  $x$ , and  $A$  represents the pre-exponential constant.) Assuming monodispersion of the particles in the medium, and that the detector captures all the light scattered by the particles in the forward direction, the concentration of the particles in the mixture can be calculated from the following relationship:  $k = 3C / 2D_p \sigma$ , where  $C$ ,  $D_p$  and  $\sigma$  represent particle concentration, particle diameter and particle density respectively.

As the particle sedimentation process is considerably slower in solid-liquid mixtures as opposed to solid-gas mixtures, the mixture homogeneity can be easily achieved by dispersion of the particles in a liquid medium.<sup>2</sup> In the present experiments, a known amount of lycopodium particles is uniformly dispersed in benzene/toluene in a test blank of diameter  $l$  ( $=1$  cm, in the present experiments), by thorough agitation of the test blank filled with the sample. A spectronic photospectrometer was used to measure the fraction of transmitted light through the sample for various wavelengths of the incident light. The uncertainty in measuring the fraction of transmitted light using the photospectrometer was estimated to be 5%. Figure 9 shows the variation of the fraction of light transmitted (at a wavelength of 700 nm) through benzene/toluene suspension of lycopodium particles with concentration. Based on these measurements, a relationship for the concentration of lycopodium particles in benzene/toluene (contained in a test blank of diameter  $l$  cm) as a function of the fraction of light transmitted through the sample can be given as follows:  $I/I_0 = \exp(-0.5 * C * l)$ .

Unlike the liquid suspension tests described above, an attempt was made to calibrate the detectors in a system as similar as possible to the eventual combustion experiment in method(ii). Toward this end, a calibration experiment was designed, similar to that described in the main text except the tube length was shortened to ten inches, on the presumption that uniformity would be easier to achieve in a shorter tube. The experimental parameters are described in Table 1. The selected frequency was based on tests done in normal gravity where the "best mixing" was observed visually. Only two detectors were used due to spatial restrictions. Instrument error and drift were checked and found to be small (less than 1% of the typical attenuated signal). Electrical noise from the high speed cameras, the lights, and the speaker was isolated and eliminated by proper shielding. Given the known tube volume and the preweighed amount of lycopodium, a concentration was calculated assuming that the particles were well-mixed and distributed uniformly throughout the tube. The validity of this assumption was checked by application of three criteria: (1) steady state: the signal at each of the two detectors was checked to determine if it was steady to within  $\pm 10\%$  for a period of 1 second (about as long as

possible in the drop tower); (2) axial uniformity: that the two detectors agreed to within  $\pm 10\%$  of their average and (3) reproducibility: the results between several drops agreed to within  $\pm 10\%$  of their average. To date, only one stoichiometry has been investigated. The results of the best drop are shown in Figure 8. It meets criteria (1) and (2). Further data collection is necessary to improve the reproducibility of the technique, and to investigate other stoichiometries to obtain an overall calibration curve.

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## Appendix 2

### Electrostatic Mixing

A new method of mixing, namely electrostatic mixing, has shown some promise of obtaining uniform particulate mixtures in a flammability tube. This alternative method of mixing works on a principle exactly opposite to that employed in electrostatic precipitators,<sup>1</sup> to obtain a clean, particle-free medium. When the particle-laden medium is ionized between two oppositely charged electrodes using a very high voltage across the electrodes, the charged particles exhibit an averaged gross motion between the electrodes and the resulting motion of the charged particles is a very strong function of: (i) high voltage applied across the electrodes, (ii) electrode configuration, (iii) electrode geometry, and (iv) electrode gap. Figure 10(i) shows a schematic of the electrostatic mixing technique. The electrodes made of 0.005" piano wire produced a vigorous motion of particles with a minimum of particle adhesion to the electrode surfaces. Several tests were made using a different number of electrodes which were placed axially along the inner perimeter of the flammability tube (25" long) and the adjacent electrodes were connected to the output from the transformer (7500 VRMS). Best mixing was observed when a total of six electrodes were employed to ionize the particle-laden air. Using more than six electrodes resulted in arcing across the electrodes whereas using less than six electrodes did not produce adequate radially uniform particle clouds. Figure 10(ii) shows a schematic of the

particle cloud and the particle path when subjected to electrostatic forces. In general, an optimal geometry and an optimal configuration of the electrodes are essential ingredients of electrostatic mixing technique. The main drawbacks of this method of mixing were observed to be: (i) occasional arcing, providing undesirable local ignition source leading to combustion of the mixture, and (ii) interference effects (such as high frequency noise) produced in auxiliary electronic measuring devices, caused by the high voltage application across the electrodes, and (iii) heavy wall adhesion of the particles.

## References

1. E.C. Barnes and G. W. Penny. "An Electrostatic Dust Weight Sampler," *J. Ind. Hyg. Toxicol.*, vol 20, p. 259, 1938.

## Appendix 3

### Particle Cluster Kinetics

Mixing of dielectric particulates generally involves charge separation processes, with corresponding particle-particle agglomeration and particle-wall attachment phenomena. Particle-particle clusters can be deagglomerated experimentally through the use of weak  $\alpha$ -particle sources (e.g. Polonium 210). Kinetics of acoustically induced particle mixing processes were experimentally reported earlier.<sup>1</sup> Assuming that the particle-cluster agglomeration/deagglomeration depends on the interaction of monomers with all other cluster sizes, a kinetic scheme (similar to that in conventional nucleation theory) was proposed.<sup>1</sup> In this appendix, an attempt is made to assess the usefulness of such a model in simulating the formation of a uniform particle cloud. The details of the model are not presented here and the reader is referred to Berlad et al, 1987.

Calculations were performed to determine the evolution of the cluster size distribution, assuming certain functional relationships for (i) cluster agglomeration rate constant ( $k_a$ ) and (ii) cluster deagglomeration rate constant ( $k_d$ ) as a function of cluster size (i.e.  $k_a = f_i(E_i, n_i)$  and  $k_d = f_i(P_d, n_i)$ , where  $E_i$ ,  $P_d$ , and  $n_i$  represent triboelectric collision energy parameter, particle deagglomeration power parameter, and the size of cluster  $i$  respectively). Initially (at time  $t=0$ ), the particle-air mixture is assumed to consist of 100 particles of cluster size ten (and the particle mass of a monomer is assumed to be unity). For one specific set of parameters,  $P_d$  and  $E_t$ , a linear relationship is assumed for the agglomeration and deagglomeration rate constants. Assuming there is no further agglomeration past the cluster size ten, an initial value problem is formulated for the rate of change of each cluster size  $i$  ( $1 \leq i \leq 10$ ) resulting in a set of ten nonlinear ordinary differential equations (subjected to the constraint that the total mass of all clusters is conserved for all time  $t$ ,

as outlined by Berlad et al, 1987 ). Solution of these equations is obtained using Gear methods. Figure 11 shows the evolution of the particle-cluster mass of various clusters as a function of time. At time  $t=0$ , the system consists of particles of cluster size ten only and after a period of time ( $t = 0.32$  sec), the particle cloud consists of monomers only. The growth and decay of all the intermediate cluster sizes are relatively short for the specific set of rate constants chosen, resulting in fast deagglomeration from cluster size ten. Thus it can be summarized that particle-particle interactions in a particle cloud can be closely simulated for any system with a proper choice of rate constants for agglomeration and deagglomeration of particle clusters.

## References

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Table 1: Calibration Study - Experimental Parameters

10 inch clear, straight lexan tube (2 inch diameter)
2 mylar diaphragms, glued to flanges
ignition section (no igniter wire)
midrange tweeter speaker (233.5 Hz)
2 optical probes, one near speaker
2.02 seconds of $10^{-5}$ g data recorded
lycopodium ( $28 \mu$ dia ) as fuel particles
an equivalence ratio of three or 186 mg of fuel
all fuel loaded into tube using polished brass rod
camera (400 frames per second), high speed motion
base reading of sensor (clear tube) held constant

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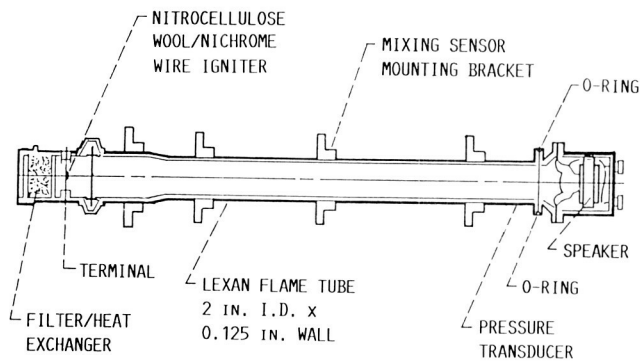


FIGURE 1. - A SCHEMATIC OF FLAME TUBE ASSEMBLY.

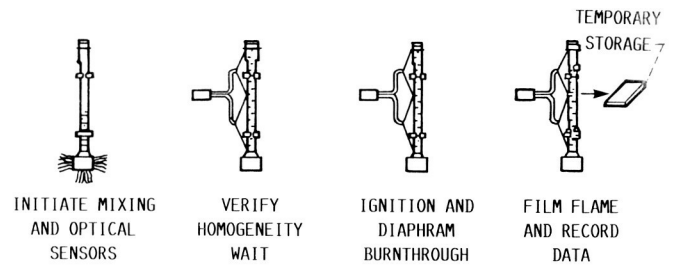


FIGURE 2. - SEQUENTIAL STAGES OF OPERATION OF THE FLAME TUBE IN A TYPICAL DROP.

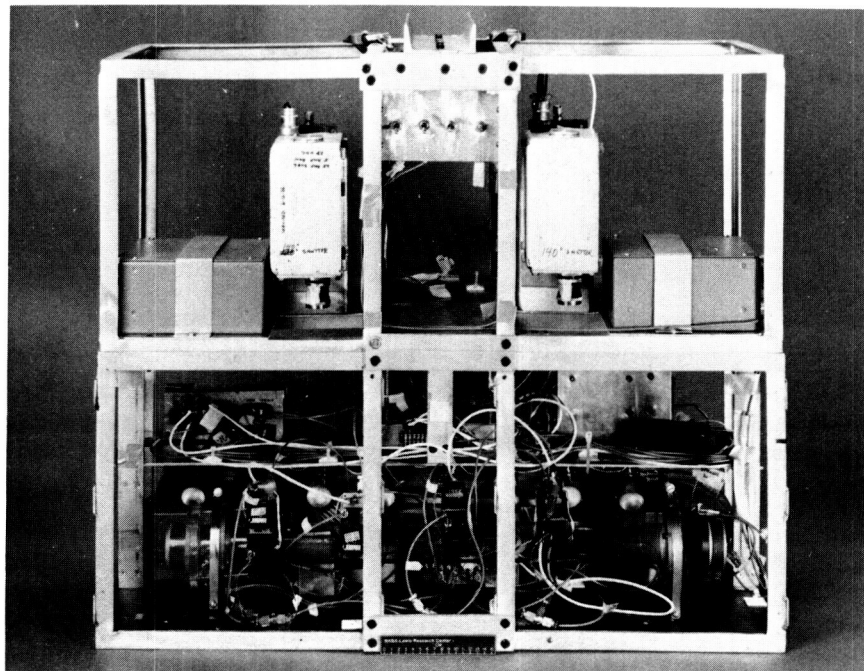


FIGURE 3. - PARTICLE CLOUD COMBUSTION EXPERIMENTAL RIG.



DROP RIG AND EXPERIMENT PACKAGE  
2.2-SECOND DROP TOWER

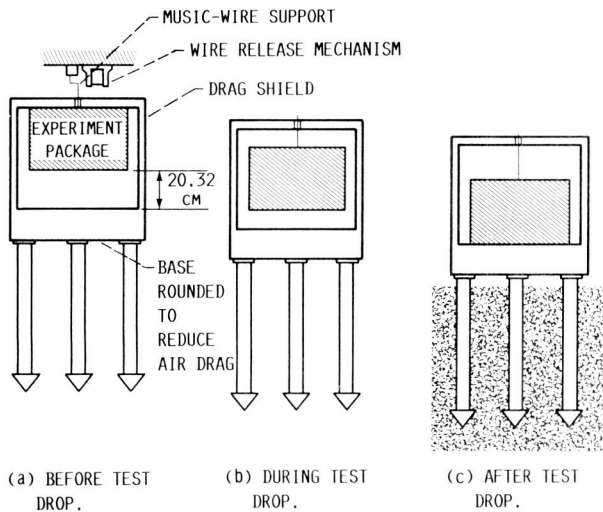


FIGURE 4. - POSITION OF EXPERIMENT PACKAGE AND DRAG SHIELD BEFORE, DURING, AND AFTER TEST DROP.

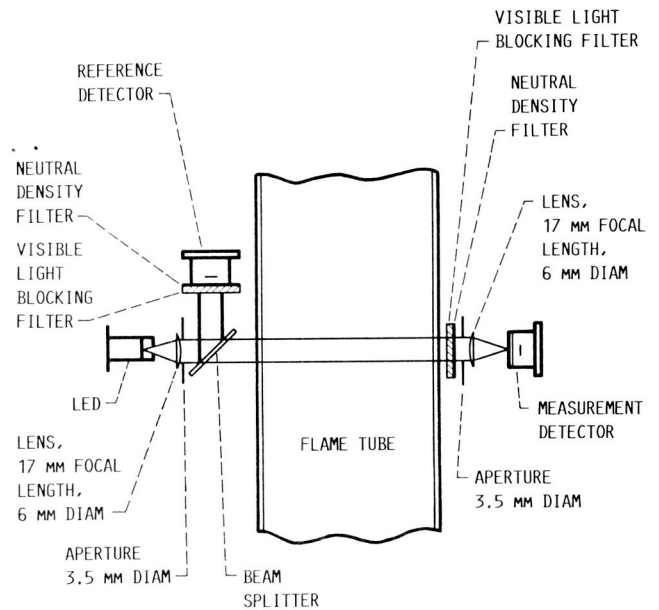
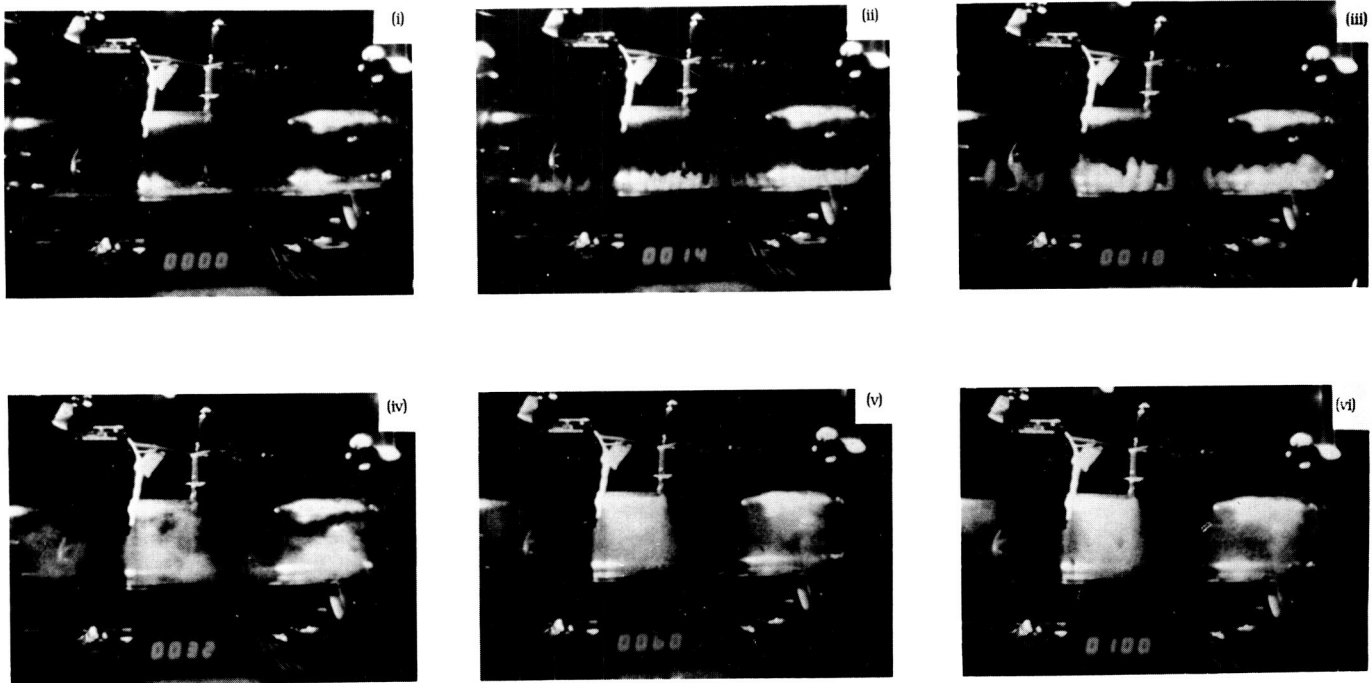


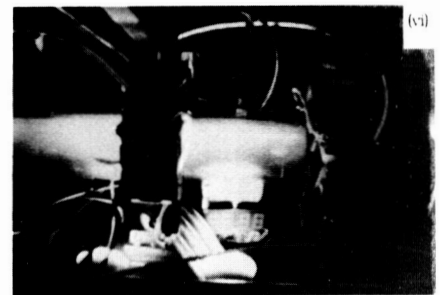
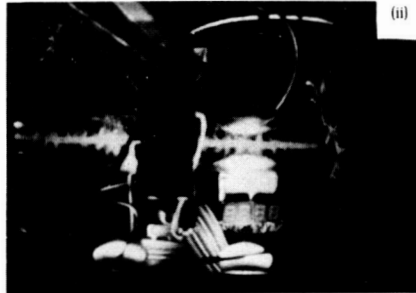
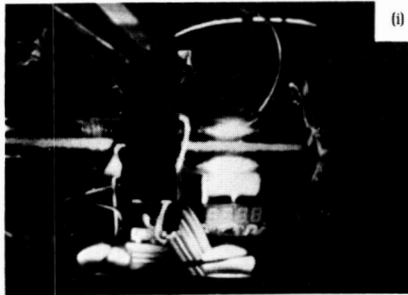
FIGURE 5. - A SCHEMATIC OF THE OPTICAL DETECTORS MOUNTED ON FLAME TUBE (25 IN.).



(a) (SIDE VIEW) 10-IN. TUBE. TIME SHOWN IS IN 0.01 SEC INCREMENTS. JET SPACING IS ABOUT 0.09 TO 0.12 IN. WITH A THICKNESS OF 0.09 TO 0.11 IN. AT  $t = 0.15$  SEC INTO THE DROP. AT  $t = 0.20$  SEC, THE SPACING IS 0.18 IN. AND THE THICKNESS IS 0.25 IN. THE SPEAKER IS TURNED OFF AT 0.3 SEC.

FIGURE 6. - SEQUENCE OF MIXING EVENTS.

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(b) (TOP VIEW) 25-IN. TUBE. APPROXIMATELY 50% OF THE TUBE LENGTH IS SHOWN. TIMER IS OBSCURED BY LIGHT GLARE. IN THE BOTTOM MIDDLE PICTURE, A PUDDLE OF UNMIXED FUEL CAN BE SEEN JUST TO THE RIGHT OF THE TIMER.

FIGURE 6. - CONCLUDED.

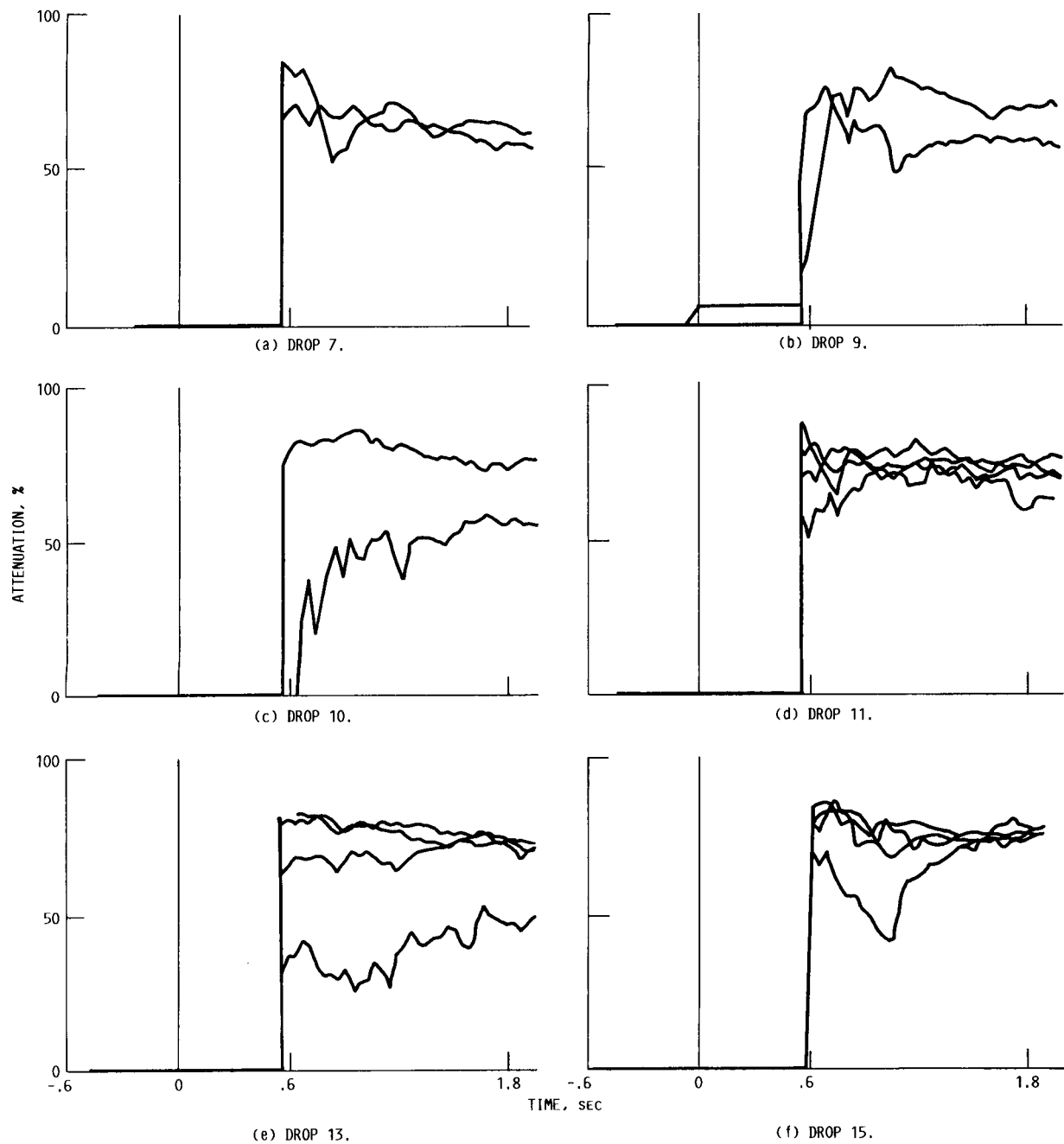


FIGURE 7. - OUTPUT FROM VARIOUS OPTICAL DETECTORS FOR VARIOUS DROPS.

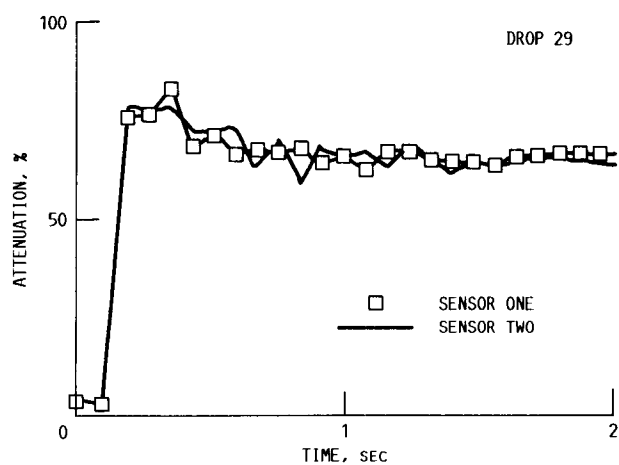


FIGURE 8. - OUTPUT FROM TWO DETECTORS USING THE CALIBRATION RIG (10-IN. FLAME TUBE).

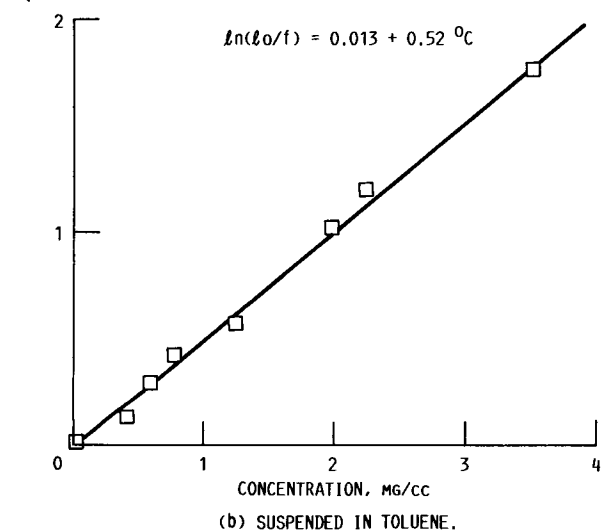
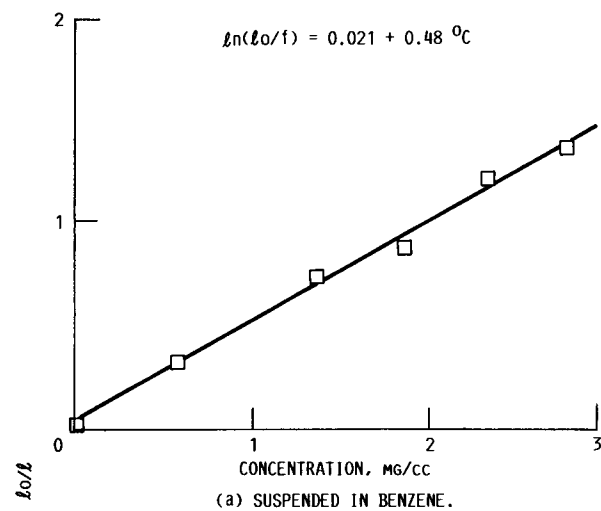


FIGURE 9. - VARIATION OF THE OPTICAL SIGNAL WITH THE CONCENTRATION OF LYCOPodium PARTICLES AT A WAVELENGTH OF 700 NM.

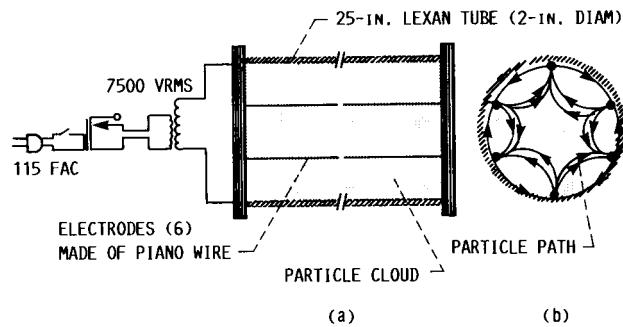


FIGURE 10. - A SCHEMATIC OF ELECTROSTATIC MIXING APPARATUS AND PARTICLE MOTION BETWEEN THE ELECTRODES.

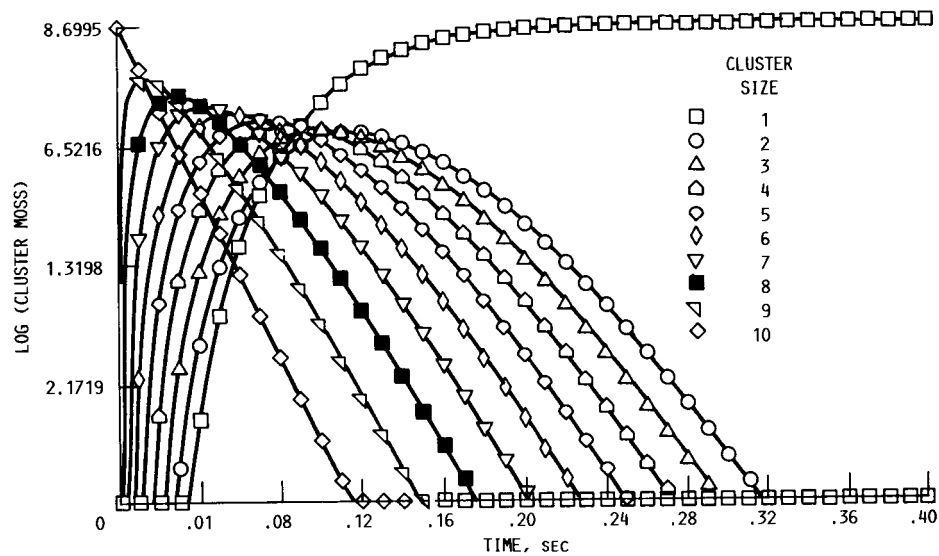


FIGURE 11. - TIME EVOLUTION OF PARTICLE-CLUSTER MASS AS PREDICTED BY THE MODEL, DURING FAST DEAGGLOMERATION FROM CLUSTER SIZE TEN.



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16. Abstract Quasi-steady flame propagation through clouds of combustible particles requires quasi-steady transport properties and quasi-steady particle number density. Microgravity conditions may be employed to help achieve the conditions of quiescent, uniform clouds needed for such combustion studies. Joint experimental and theoretical NASA-UCSD studies have been concerned with the use of acoustic, electrostatic, and other methods of dispersion of fuel particulates. Results of these studies are presented for particle clouds in long cylindrical tubes.					
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